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ARTICLE IV.

TIDAL PHENOMENA OF THE ST. JOHN RIVER AT LOW SUMMER LEVEL.

BY A. WILMER DUFF, M. A.

(Read March 2nd, 1897.)

I. Free and Forced Vibrations.

The waters of the earth have two somewhat different kinds of motion. There are, first, the steady motions, such as the Gulf Stream, caused ultimately by the heat which we receive from the sun. Secondly, there are motions of vibration, including waves of various kinds and tides. This second class also admits of an important sub-division. Firstly we have those motions of vibration whose rates are determined merely by the properties of water (especially its mass) and by its weight, or the force which the earth exercises on it; these motions being analagous to the motion of a pendulum, whose rate is determined by its length and the earth's attraction. This kind of vibratory motion we may call the *free* or natural vibrations of the water. But there is a second class of motions of vibration whose rates are determined by the motions and attractions of bodies beyond the earth, especially the moon and sun. These motions we may call the *forced* or artificial vibrations of water masses. When we speak of tides, we are inclined at first to think of them as merely forced vibrations; but, in reality, the forced vibrations give rise to free vibrations and the two kinds of vibration are quite inseparably mixed up in tidal phenomena. For instance, the highest authority on tides (Lord Kelvin) regards the tides of the English Channel as mostly a free vibration of the water, see-sawing or teetering about a line passing from Portland to Havre; and William Ferrel (probably

the chief authority in America) thinks that the tides of the deep water of the North Atlantic may be an eastward and westward swinging motion, like the "wish-wash" of water in a wash-bowl. In one case only have we a motion of vibration that belongs to one only of these two classes, namely, the case of moderate sized lakes; for their motions are nearly altogether free vibrations, and it is only in very great lakes that forced vibrations can be discovered; for instance, the tides of Lake Michigan only amount to between two and three inches.*

II. Tides in Rivers.

Remembering this distinction between free and forced vibrations, let us apply it to the case of a river. Are there any forced vibrations in rivers; that is, any motions produced by the direct attractions of sun or moon on the waters of the rivers? Reason will be adduced later for believing that, in the case of the St. John river at least, there is nothing such; but it cannot be denied that in the case of a very large river like the Amazon, whose course is directly east and west, there may be such a direct forced vibration. But there is in most rivers that enter the ocean a *secondary* forced vibration; that is, a fluctuation of the level of their waters produced by a periodical rise and fall of the level of the ocean at the mouth. This distinction is sometimes put in this form, that there is no true tide in the St. John river, only a "backing-up;" but such a way of putting it is hardly justifiable. It is true that as the level of the water at the mouth rises, the speed of the stream must decrease, and as there is still practically the same supply of water from the parts of the river farther up, the level must in consequence rise progressively up stream. This is what is meant by a "backing-up." But there is also a flow of salt water up stream for a considerable distance from the mouth, a flow that differs in no respect from the flow of water up the Bay with the incoming tide. Now we have seen that we cannot limit the word tide to direct forced vibrations

* T. D. Graham, Vol. xiv., A. A. A. S., 1860.

only, for there is none such anywhere; nor can we limit the word tide to cases in which forced vibrations and free vibrations are mixed, for it is probable that in the Bay of Fundy itself we have mostly, if not altogether, a free motion of the water, started no doubt by the forcible motions imparted to adjacent parts of the Atlantic. Tides are in fact those forced motions or free motions which may be traced back ultimately to the attractions of sun and moon. And in this sense it is evident that the rise and fall in a river is a true tide. Thus the tides in the River St. John are a mixture of a "backing-up" and a flow of salt water upwards, but this flow of salt water never extends to anything like the distance at which the "backing up" is perceptible. Along with these motions we have complications produced by wind effects and barometric effects. I am aware that some points in this account may be disputed, but I shall attempt to justify the statements in the course of what follows.

III. The River St. John.

It will be necessary to state briefly a few of the physical features of the river which seem of most importance in the present connection. We shall only be concerned with the last ninety miles of its length. Just above Springhill (ninety miles from mouth) rapids occur. From Springhill to the mouth of the Belleisle, the general course of the river is between east and south-east, and the river is comparatively shallow and sluggish. Below this comes the Long Reach, a straight clear part of the river, the general direction of which is south-west. This ends at Westfield and the river again takes a southerly direction, enlarging greatly to form Grand Bay and receiving on the east the waters of the Kennebecasis, a large, wide tributary. Below Grand Bay, the river greatly contracts at the Narrows, expands again at Indiantown, then contracts again and meets with short "rapids" and then rushes through a short and very narrow gorge (only one hundred yards wide) into St. John harbour. The term "Falls," often applied to this outlet, more properly belongs to rapids above the outlet. The occurrence of islands is of impor-

tance. From Springfield to Oromocto few occur, from Oromocto to Oak Point they are large and numerous, and below Oak Point there are but few.

IV. Points to be Ascertained.

While the St. John offers no such striking phenomena as the Petitcodiac and other streams near the head of the Bay of Fundy, yet, when its great size and remarkable outlet and the striking tides of St. John harbour are considered, it should, from the tidal standpoint, be one of the most interesting of rivers. A comprehensive study of its tides at various representative points should tells us: (1) The difference of time between high water and low water at such points and high water and low water at St. John. (2) The proportion which the range of tide bears to the corresponding tide at St. John. (3) The nature of the tidal rise and fall. (4) The effects of varying cross-section, depth, presence of islands and tributaries on the extent and time of tide. (5) The effect of the remarkable outlet. (6) The effect of varying depth of river with changing seasons on the preceding. (7) The effect of winds. There is at present practically no information, at least in print, to be had on any of the above points. To get anything like complete data, on even one of the above points, would demand much time and patience. What follows can only pretend to be somewhat disjointed information on nearly all of the above heads. It must be remembered that all of the following notes were made at low summer level. Towards the end of the summer of 1896 the river fell to a very low level. To fix the level by a semi-permanent reference point, on August 9th I found mean water level of Fredericton to be twenty-four feet two inches below the south-west corner of the west pier of the iron railway bridge. From the levellings of the New Brunswick railway, Mr. Moses Burpee found that a certain reference point at Fredericton was forty-four feet ten inches above mean sea-level at St John. Prof. Dixon has kindly aided me by levelling from Mr. Burpee's reference point to the corner of the pier mentioned, and finding the latter to be three

feet four inches lower than Mr. Burpee's reference point. From this I deduce that the south-west corner of the west pier of the bridge is forty-one feet six inches above mean sea-level at St. John; and that on August 9th the mean water level at Fredericton was fourteen feet four inches above the mean sea level at St. John. These figures may be of some future use for reference and they are given for what they may be considered worth. Exception may be taken to the use of railway levellings for such a purpose, but other data are not to be had at present. I am indebted to Dr. Harrison, of the University of New Brunswick, for Mr. Burpee's figures.

V. Tide Gauge Used.

For the purpose of the following work I used a self-recording tide gauge of a simple type designed by myself and made with the assistance of Mr. H. White of Fredericton. As a description may be of use to others I give the following brief account of it. It consisted of a float to rise and fall with the water and a vertical drum driven by a clock, the parts being so arranged that a pencil attached to the float traced a curve on a sheet of paper wrapped around the rotating drum. The details and dimensions were as follows:

The float consisted of a cylindrical can plain at the top and with a conical lower end, the lower end being loaded with shot to give the float greater stability in the water. The diameter of the can was five inches and its length without the conical end five inches, with the conical end seven and a half inches. A brass tube was soldered axially through the can. Through the tube a brass rod passed loosely so that the float might slide up and down the rod as an axis. This axis was clamped in the frame-work of the machine, so that it might be removed and cleaned. Above the rod came the rotating drum, a cylinder of wood twelve inches long and three inches in diameter. The upper end of this made friction connection with a spring clock by means of a small axial rod fastened to a brass plate which was screwed to the wooden drum. The lower

end rested on a spring by means of a similar axial rod having a conical point which turned with very little friction in a conical hole in a brass plug attached to the spring. The purpose of the spring was to keep the cylinder pressed tightly against the clock. A long springy piece of brass was soldered by its lower end to the side of the float and its upper end carried a pencil which pressed lightly against the cylinder. It is easily seen that surface waves might move the float and so obscure the tidal record; hence the whole instrument was enclosed in a long, narrow, vertical box which leaked slightly at the bottom. Thus the water level in the box changed with the slow rise and fall of the tide but surface waves had no effect. The machine was held at the proper level in the water by being solidly clamped to an iron stake driven in the ground.

In preparing for an observation, a sheet of white paper was wrapped around the cylinder. The cylinder was then put in place and the pencil arranged so as to press against it. The exact time of beginning and ending the record being noted, the time corresponding to any particular point on the curve could be deduced after the paper was removed.

VI. Curves Obtained at Springhill.

The first point at which this instrument was used was immediately above the rapids above Springhill on July 21st and 22nd. The line traced in twenty-four hours indicated a fall of thirteen-sixteenths of an inch, but differed by less than one-sixteenth of an inch from a straight line, indicating that absolutely no tides are propagated above these rapids, at least along the right bank. The next point chosen was just below the rapids, about a quarter of a mile above the Springhill hotel. A twenty-seven hour record was taken on July 23rd and 24th. This showed in a remarkable way an effect frequently afterwards noticed, the great influence of wind. From 6.30 p. m. to 9 p. m. of the 23rd, a strong wind blew down stream, and during this time the pencil traced almost a straight line. At 10.30 it rose about a quarter of an inch, and then fell smoothly to low water at 3 a. m., and rose to

high water at 8 a. m.; the range from high water to low water being four and a half inches. The instrument was then removed to be slightly altered, and at 8 p. m. of July 28th it was replaced at the same point, and thenceforward a continuous record was obtained until August 6th. This would have given eighteen high waters and seventeen low waters, were it not for the fact that the weather, which, until the 31st, was calm, suddenly became stormy, with winds of as much as twenty miles an hour from the north-west, that is, from nearly exactly up-stream. These were sufficient to totally obliterate the ordinary tidal rise and fall and give curves whose ragged irregularities represented faithfully every variation in speed and direction of wind. In the complete record which accompanies this I may point especially to 7 p. m. of the 4th, 8 a. m. of the 5th, 1 p. m. of the 30th, and 1 a. m. of the 2nd. The corresponding wind velocities, kindly supplied by Dr. Harrison, have for comparison been placed at the top of the record. A curious hump in the curve at 10 p. m. of the 5th was explained by a sudden gust of wind which, Dr. Harrison informed me, was indicated by the recording wind gauge just at that time. These facts are interesting as indicating the very great effect which wind has on water in a somewhat confined basin. The effect would, of course, be still more marked in the case of lakes. This is of interest in connection with the other paper (on secondary undulations) presented to the Society.

The smoothness of the curves in calm weather is of importance as indicating that we have at Springhill no true forced vibration of the water, produced directly by lunar influence, but only a free derived waved started by the rise and fall at St. John. A mixture of both would give irregularities in the curve.

VII. Time and Amount of High Water at Springhill.

In the curves obtained at Springhill, there are in all twelve fairly well marked high waters, the others being unreliable on account of wind disturbances. Of these, six were obtained during very calm weather and six others during windy weather. From the former, Table I has been calculated. Column 2 gives the

range of tide at Springhill, 3 the range of tide at St. John, 4 the percentage of the St. John tide that reaches Springhill, 5 the difference between the time of high water at Springhill and high water at St. John, 6 the difference of the time of low water at Springhill and low water at St. John. The times of high water at St. John were obtained from the records of the Kelvin Recording Tide Guage, for access to which I have to thank

TABLE I.

Time and Amount of Tide at Springhill.

Date.	Range at Springhill.	Range at St. John.	Percentage at Springhill	Difference of times of H.W. at Springhill and St. John.	Difference of times of L. W. at Springhill and St. John.
July 23	4.5 in.	22.1 ft.	1.70	9 h.—19m.	11h.—49m.
28	3.94 "	20.4 "	1.61	9 h.—15m.	11h.—18m.
29	4.12 "	20.0 "	1.72	9 h.—18m.	10h.—57m.
30	4.25 "	20.6 "	1.72	9 h.—30m.	11h.— 3m.
30	3.62 "	19.6 "	1.54	9 h.—15m	10h.—45m.
31	3.32 "	18.1 "	1.52	9 h.—20m	....
Mean	3.96 in.	20.1 ft.	1.63	9 h.—20m.	11h.—9m.

TABLE II.

Time and Amount of Tide at Springhill.

Date.	Range at Springhill.	Range at St. John.	Percentage at Springhill	Difference of times of H. W. at Springhill and St. John.	Difference of times of L. W. at Springhill and St. John.
Aug. 3	4.06 in.	16.25 ft.	....	9h.— 9m.	10h.—45m.
4	4.32 "	14.55 "	....	9h.—28m.	11h.—10m.
4	4.19 "	16.4 "	....	9h.—20m.	11h.—55m.
5	2.87 "	15.0 "	....	9h.—36m.	11h.—50m.
5	3.00 "	15.0 "	....	9h.—1 m.	11h.—13m.
6	....	18.0 "	....	9h.—5 m.	11h.—20m.
Mean	....	15.9 ft.	....	9h.—16m.	11h.—22m.

Mr. D. L. Hutchinson. Table II is similar to Table I, except that it is calculated from the less reliable results obtained during windy weather. The following are the more important points brought out by these tables:

(1) *The Time of High Water at Springhill.* Just at high water or low water at any place the level changes very slowly. Hence it is difficult to be quite certain of the exact moment of change. Remembering that this remark applies to both the St. John and the Springhill records, the close agreement among the results of column 5, which gives the interval between high water at Springhill and high water at St. John, must be considered very satisfactory. The mean interval is nine hours and twenty minutes, the greatest divergence from the mean is ten minutes, and the next greatest five minutes. The "probable error" is only one and a half inches. The second series being made in windy weather, do not agree so well among one another, but give a mean of nine hours and sixteen minutes, differing by less than one per cent from the preceding. The mean tidal range at St. John was twenty feet in Series I and sixteen feet in Series II. Hence the former results may be taken as fairly representative of spring tides and the latter as neap tides. The mean tidal range is twenty-five per cent greater in Series I than in Series II, and yet the time of passage of high water from St. John differs by less than one per cent. We seem justified in concluding that the interval between high water at St. John and high water at Springhill is practically independent of the tidal range. This should be remembered in connection with the results obtained at other points on the river.

(2) *Amount of Tide at Springhill.* From Series I we see that when the mean range of tide at St. John is twenty feet, that at Springhill is four inches or 1.63 per cent or about one-sixtieth of the range at St. John. Moreover, the range at Springhill is (allowing for wind disturbances) proportional to that at St. John. This is otherwise evident from the principle of the superposition of small motions.

(3) *Time of Low Water at Springhill.* From Table I it is seen that low water at Springhill occurs on an average eleven hours and nine minutes later than low water at St. John. Hence it takes low water one hour and of rty-nine minutes longer to travel from St. John to Springhill than it does high water. This is shown in another way by the shape of the Springhill curves. It will be noticed that in all cases the curves are steeper on one side of high water than on the other, the tide rises faster than it falls, so that a low water always comes closer to the succeeding high water than to the preceding. In fact, the average time from low water to high water is only five hours and seventeen minutes, while that from high water to the next low water is seven hours and seven minutes. This relative delay of low water is due to one of the differences between wave motion in a shallow river and wave motion on the ocean. In the former the more elevated parts of a wave always travel faster than the less elevated or the depressed parts. In fact, if v be the velocity of any part of a wave whose elevation above the mean level is h, and if H be the depth of the river

$$v = c\left(1 + \frac{3}{2}\frac{h}{H}\right)$$

In this, c is of course the value of v, for parts of the wave for which h is zero; that is, for parts of the wave midway between crest and trough. In the parts of the wave below mean water level h is negative. Hence v is greater for the crest than for the trough; that is, greater for high water than for low water. Thus low water keeps lagging farther and farther behind the high water ahead, and approaching the high water behind. This process may go so far that the front of the tide wave becomes nearly vertical and then we have a bore as in the Seine, Petitcodiac and many other rivers.

With this greater steepness of the front of the tide wave another peculiarity is often developed. The rear slope of the wave may first become straight and then actually recurved. This is hardly shown in any marked degree on the St. John River, although the rear slope sometimes approximates to a

straight line. The depth of the river decreases too gently and uniformly to show these more marked features often shown in tidal rivers.

VIII. Form of Tide Wave at St. John.

While the change of form referred to in the preceding is a well known feature in rivers, I do not know that attention has ever been called to the fact that the same thing may happen even in large bays like the Bay of Fundy. It occurred to me to examine carefully the tide record at St. John to see if low water

Table III.

Delay of Low Water at St. John.

Time from H.W. to L. W.		Time from L. W. to H.W.		Delay of L. W.	Time from H.W. to L.W.		Time from L.W. to H.W.		Delay of L. W.
hrs.	min.	hrs.	min,	min.	hrs.	min.	hrs.	min	min.
6	25	6	10	7.5	6	10	6	5	2.5
6	20	6	5	7.5	6	30	6	2	14.0
6	33	5	59	16.0	6	11	6	12	—0.5
6	10	6	0	5.0	6	22	6	3	9.5
6	13	6	9	2.0	6	30	6	0	15.0
6	33	5	57	18.0	6	15	6	0	7.5
6	25	5	55	15.0	5	16	6	6	5.0
6	33	5	53	20.0	6	18	6	2	8.0
6	15	6	0	7.5	6	23	6	5	9.0
6	18	6	0	9.0	6	23	6	0	11.5
6	24	6	3	10.5	6	22	6	5	8.5
6	18	6	10	4.0	6	30	5	58	16.0
6	13	6	7	3.0	6	30	6	10	10.0
6	18	6	12	3.0	6	25	6	2	11.5
6	8	6	7	0.5	6	28	6	17	5.5
6	13	6	20	3.5	6	18	6	10	4.0
6	22	6	10	6.0	6	20	6	2	9.0
6	18	6	10	4.0	6	13	6	5	4.0

Mean delay, 8 min.

falls exactly midway between two high waters. Table III gives the time from high water to low water and from low water to

high water for all the tides in a month whose exact time of high water to low water could be read accurately enough to be the basis for an estimate. Out of the thirty-six complete tides there recorded, thirty-four show a greater length of time from high water to low water than from low water to high water. The mean delay of low water is eight minutes, or the time from high water to low water is on the average sixteen minutes greater than the time from low water to high water. It should be noted that this delay of low water in St. John harbour is not due to the fact that the harbour is at the mouth of a large river; this would tend to have exactly the opposite effect. For, shortly before low water would naturally occur, the inflow from the river neutralizes the outflow into the bay and thus causes the tide to turn earlier or the low water to come earlier. On the other hand, the upflow into the river just before high water would occur neutralizes the inflow from the bay and so causes high water to occur earlier. Now if high water and low water were thus hastened equally, there would be no change in the time from high water to low water or from low water to high water. But since on the whole there is a greater downflow from the river than upflow into it, it is clear that the river must hasten low water in the harbour more than it hastens high water. Hence we may conclude that did the river not exist, the delay of low water in the harbour would be slightly greater than eight minutes. No doubt part of this delay must occur whilst the tide is passing from Mispec Point inward. How much of it occurs during the passage of the tide up the bay must remain an open question.

IX. Results at other Points on River.

The observations made at other points are given in Table IV and summarized in Table V. These tables show at Springhill, Fredericton, Oromocto, Gagetown, Oak Point, Westfield and Indiantown, (1) the mean spring-range (it being assumed that the spring-range at St. John is twenty-seven feet); (2) how much later high water is at each point than at St, John; (3) how much low water is delayed compared with high water. The last

column of Table V seems to show that between Indiantown and Oak Point the low water is delayed over twenty minutes compared with high water; between Oak Point and Oromocto low water travels as fast as high water, and between Oromocto and Springhill low water again loses half an hour.

TABLE IV.

Place.	Date.	Tide in Inches.	St. John Tide in feet.	Percentage of St. John Tide.	H. W. later than at St. John.	L. W. later than at St. John.
					hr. min.	hr. min.
Fredericton...	July 24	5.3	22.1	2.0	8 — 39	10—17
	Aug. 21	5.6	19.5	2.4	8 — 47	10—49
	" 22	6.1	22.1	2.3	8 — 59	10—3
Oromocto....	" 10	6.6	24.5	2.2	8 — 0	8—48
	" 11	7.9	25.7	2.6	7 — 55	8—24
Gagetown ...	" 11	9.1	25.1	3.0	5 — 42	6—20
	" 12	9.6	25.5	3.1	5 — 37	6—13
Oak Point ...	" 12	12.0	25.2	4.0	3 — 18	3—57
	" 13	13.8	24.6	4.7	3 — 11	4—7
Westfield....	" 14	18.5	23.5	6.5	2 — 26	3—18
	" 14	......	23.6	.....	2 — 32	......
Indiantown....	" 31	16.0	16.6	8.0	2 — 2	2—5

TABLE V.

Place.	Distance from Indiantown.	Mean Spring Range.	Mean Percentage of St. John Range.	H. W. later than at St. John.	Delay of L. W.
				hr. min.	min.
Springhill	90	5.2	1.6	9 — 20	55
Fredericton	83	7.1	2.2	8 — 45	49
Oromocto	73	7.8	2.4	7 — 57	20
Gagetown	48	9.7	3.0	5 — 40	24
Oak Point...	25	13.9	4.3	3 — 15	24
Westfield.........	10	21.0	6.5	2 — 30	24
Indiantown	0	25.9	8.0	2 — 2	0

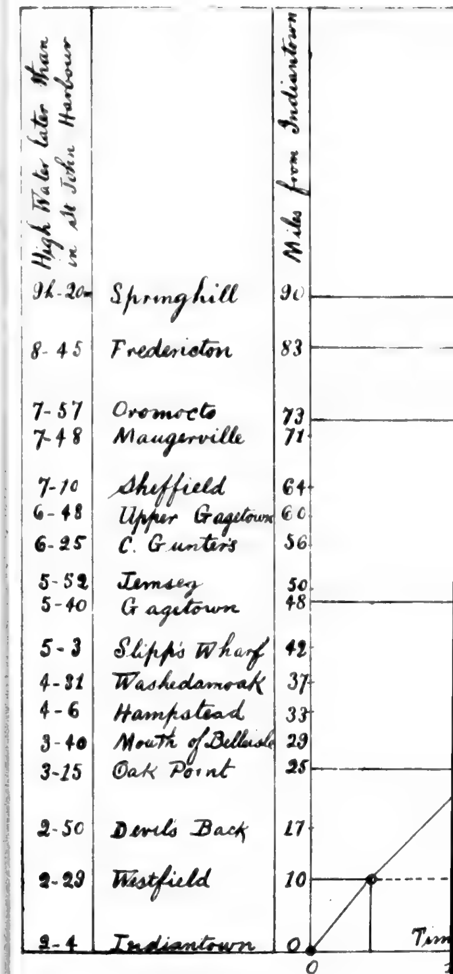
X.—Rate of Progress of High Water up River.

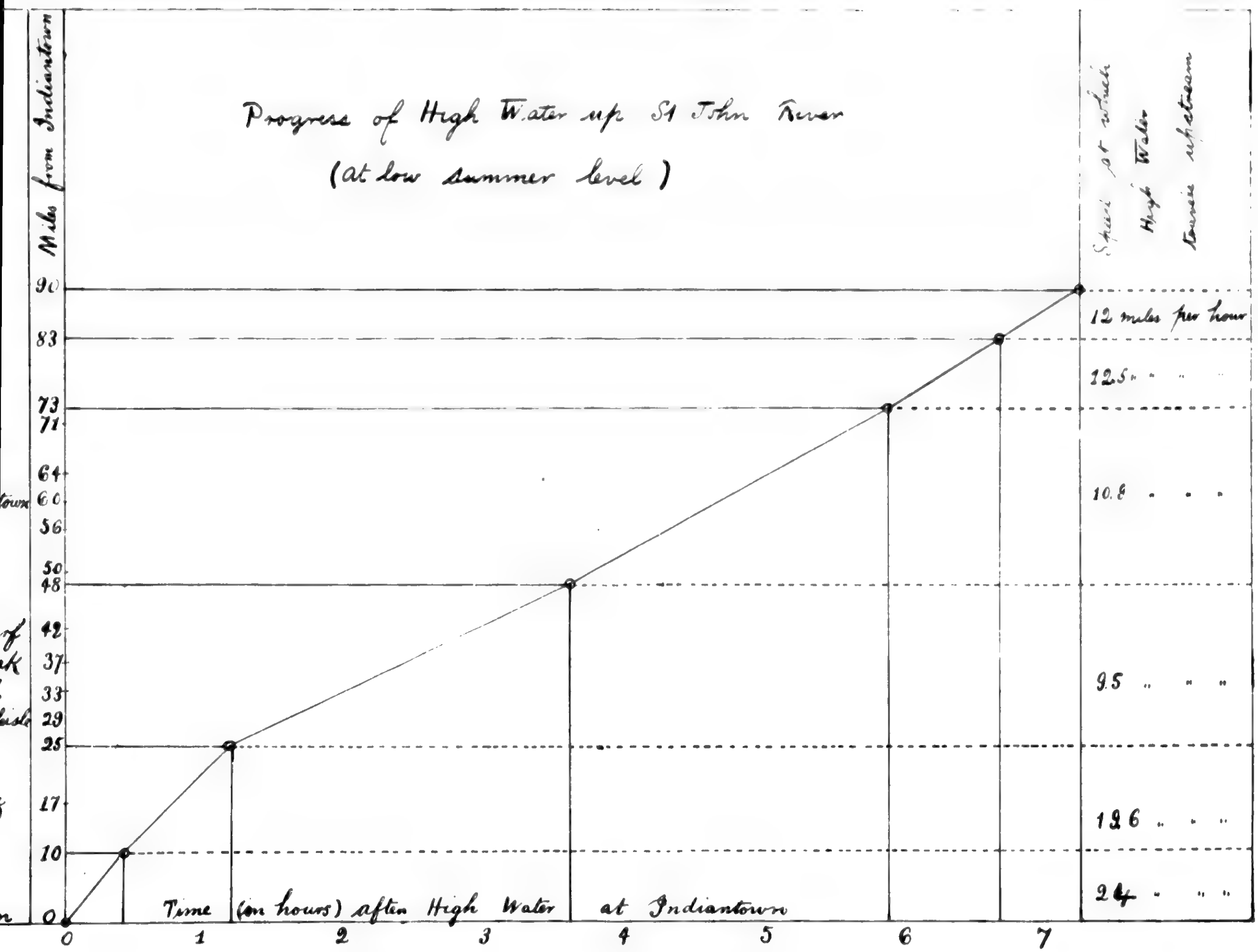
To show the speed with which high water travels up river I have plotted the results on cross section paper. Indiantown is taken as origin or starting point. Times after high water at Indiantown are represented by horizontal lines or abscissæ, and the distances which high water has progressed in those times are represented by vertical lines or ordinates. The points on this chart corresponding to the seven stations of observation are joined by straight lines. The slope of this broken curve at any point represents the speed of the high water at that point. This shows at a glance that, whereas the speed is much less between Oak Point and Oromocto than it is between Indiantown and Oak Point, it increases again between Oromocto and Kingsclear. In fact the average speed of high water is:

Between Indiantown and Oak Point — 20 miles an hour.
" Oak Point and Gagetown — $9\frac{1}{2}$ " "
" Gagetown and Springhill — $11\frac{1}{2}$ " "

It is interesting to compare this with the fact, stated in the preceding section, that the delay of low water is greatest between Indiantown and Oak Point, and between Oromocto and Springhill, but is at least very small between Oak Point and Oromocto. Again both of these statements seem connected with the fact noted earlier that it is between Oak Point and Oromocto that islands are numerous and greatly interrupt the course of the river. Hence we seem justified in concluding that irregularities and obstacles in a river retard the progress of high water, but do not delay low water as compared with high water.

I have also plotted a curve representing how the amount of tide from point to point of the river varies with the distance from Indiantown. Excepting the highest point, Springhill, the points lie roughly on an exponential curve, indicating that each mile produces roughly the same percentage decrease of tidal rise. This would seem almost obvious beforehand, and need hardly be discussed further.




Progress of High Water up St John River
(at low summer level)
Miles from Indiantown
90
83
73
71
64
60
56
50
48
42
37
33
29
25
17
10
0
Time (in hours) after High Water at Indiantown
0
1
2
3
4
5
6
7
12 miles per hour
12.5
10.8
9.5
12.6
24

XI. Time of High Water at any Point on River.

The broken curve connecting times of high water at the seven points of observation and their distances from Fredericton enables us, given the distance of any point whatever from Indiantown, to find how much later high water occurs at that point than at St. John. We have only to find the point on the curve whose ordinate is the distance from Indiantown, then the abscissa of that point is the time its high water occurs later than

Table VI.

Time of High Water at various points.

Distance from Indiantown.	Name of Place.	H. W. later than H. W. in St. John Harbor.	Intermediate Points.
		hrs. min.	
0	Indiantown.	2 — 4	
10	Westfield.	2 — 29	
17	Pitt's Landing, (Devil's Back).	2 — 50	To column 3 add 3 minutes per mile
25	Oak Point.	3 — 15	
29	Mouth of Belleisle, (Palmer's Point).	3 — 40	
33	Hampstead.	4 — 6	
37	Mouth of Washademoak.	4 — 31	
42	Slipp's Wharf.	5 — 3	
48	Gagetown	5 — 40	
50	Jemseg, mouth of Grand Lake.	5 — 52	To column 3 add 5 minutes per mile
56	Charles Gunter's.	6 — 25	
60	Upper Gagetown.	6 — 46	
64	Sheffield.	7 — 10	
71	Maugerville.	7 — 48	
73	Oromocto.	7 — 57	
83	Fredericton.	8 — 45	
90	Springhill.	9 — 20	

the time of high water at Indiantown. Now a knowledge of the exact time at which high water may be expected at any point is (at least so residents along the river frequently informed

me) a matter of considerable importance especially as regards setting nets for fishing, getting grounded vessels afloat and other such practical purposes. Hence, although my motive in this enquiry has been purely scientific interest, I have thought it worth while to give in Table VI the interval between high water in St. John harbor and high water at seventeen points of importance on the river. This table, together with a McMillan's Almanac, will enable a resident on the river to anticipate high water quite as accurately as a resident in St John can at the present time; for the figures in Table VI cannot be more than ten or twelve minutes in error, probably much less, and this is a smaller amount than the error incident to the prediction of high water in St. John harbor at present. It may be well to repeat that this table applies to either spring or neap tides during low summer level. It remains to be seen whether it will apply to the river when full, in the spring or early summer. I think it can be safely predicted that the difference will not be great; for, while the greater speed of the water will naturally retard the progress of high water, the greater depth of the river will cause a wave, whether up or down, to travel with greater speed; and the two effects, depending on the same cause, will tend to neutralize one another. This, however, is a point that should be settled by observations in springtime.

XII. Effect of Narrow Outlet of River.

The most important tidal effect due to the remarkably narrow outlet of the river is the great delay of high water at Indiantown—two hours very closely,—although Indiantown is only a mile from the harbour. As the water rises in the harbour it must attain the level in the river above the rapids before much rise can occur at Indiantown. After that, as the supply of water from the harbor and bay is unlimited, while the large basins above Indiantown have a great capacity, the narrow outlet under the bridge is totally inadequate to keeping the levels above and below equal, so that for two hours after the water has reached its maximum level at St. John, and has

begun to fall, it is still running up river. At low water the converse happens, that is, the level at Indiantown keeps falling nearly until the part below the rapids has been filled up to the level above the rapids. It seems, however, not a little remarkable that the delay is so exactly the same for high water and low water. This account must be admitted to be very imperfect, as I had very little time for exact observations, except as regards the time of high water and low water at Indiantown.

XIII.—Tidal Currents.

In the preceding I have not paid any attention to the currents which form so important a part of tidal phenomena. The subject is one of great complexity in such a river as the St. John. Two remarks may however be made.

First it is rather a common mistake to suppose that there must exist a flow of saltish water as far up the river as tides can be detected. Two grounds are sometimes advanced for this view. The first is that a tide means a flow of water and there must be a flow of water as far up as there is a tide. This statement is true, but the deduction is unsound ; for a tide, whether in a river or on the ocean, is a wave, and a wave may pass on for thousands of miles while the water at any place only makes short excursions, going forwards as the crest of the wave passes by, and backward as the trough passes. No one would claim that the water at the mouth of the Bay of Fundy travels the whole way to the head with the tide, for if so a vessel could float that distance in one tide. The second ground sometimes advanced is that there must, by the principles of hydrostatics, be salt water as far up steam as the point at which the bed of the river is on a level with the mean level of salt water at the mouth of the river ; and that hence up to the head of the tides there will be an undercurrent of salt water up and an overcurrent of fresh water down. But it is impossible that two such layers should co-exist for a hundred miles without mixing. Again in many rivers such as the Amazon, La Plata, and Forth it is known that the tides extend a long distance further up than the point at which the level of the

bed of the stream is the mean water level at the mouth.* But even without this the evidence is complete; for I have obtained specimens of water from both surface and bottom at Fredericton and Indiantown at high water and their specific gravities reduced to 0° C. I find to be

Fredericton,	Surface water, ...	1.0005
	Water from bed, ...	1.0003
Indiantown,	Surface water, ...	1.0054
	Water from bed, ...	1.0109

Thus to within one-fiftieth of one per cent the water at Fredericton has the same density at surface and bottom. Even at Indiantown the process of mixing of salt water and fresh water is well advanced, for the density of the surface water is raised to 1.0054, and that of the bottom is lowered from about 1.026 which is the average density of sea water to 1.0109. When the diffusion has proceeded thus far even at Indiantown, it is evident that the tide will not have progressed many miles up river before the mixing is practically complete. How far salt water actually does travel up stream cannot be stated. It has been known as far as Gagetown.

As regards the amount of tidal current, I may note that on the morning of Monday, August 4th, I saw at Oromocto a log float one and a quarter miles up stream in the main channel in two and a half hours. That was at high water of a spring tide. That it was an unusual amount of up-current was evident from the extent to which it seemed to puzzle a ferryman. Also at Fredericton on Aug. 22nd, at 4 p. m., I observed a feeble current up. A careful examination of this whole question would be of great importance in such discussions as to whether the discharge of sewage into the river below Fredericton could affect the waterworks above the city.

In conclusion I wish to express my indebtedness to Mr S.W. Kain and Mr. Percy G. Hall, of the Natural History Society, also to Mr. Thomas Loggie, of Fredericton, Professor Davidson, of Fredericton, and Mr. E. T. P. Shewen, of St. John, besides the gentlemen previously mentioned, all of whom have been so kind as to supply me information or assistance.

* See Young's General Astronomy, p. 477. Airy's Article, Tides and Waves—Ency. Metropolitana.